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Method and Apparatus for Determining Characteristics of  
Components of a Communication Channel

This invention refers to a method for determining  
5 characteristics of components of a communication channel and  
in particular of a satellite communication channel.

After a successful launch of a new communications satellite,  
it is essential to test the communication's subsystem while a  
10 spacecraft is in orbit so as to compare with prelaunch data  
in order to ensure that no impairment has resulted from the  
stress of the launch and to verify that the spacecraft  
payload is compliant with the specification sought.

As to the in-orbit test technology it has to be considered  
that the spacecraft has to be operational very quickly while  
not sacrificing the number of tests that have to be performed.  
Thus, microwave measurement techniques with more powerful  
computers and software technology have been used to automate  
20 the beginning of life test of a new communications satellite.

In order to give an understanding of the tests which have to  
be performed, it has to be noted that a communication channel  
is in general separated in adjacent channels with the help of  
25 adequate filters. The channel filters fulfill two distinctive  
tasks: in first place, the specific channel filters have to  
avoid an interference from and to adjacent channels, and  
secondly, the signal passing the channel must not be subject  
to distortion due to filter characteristics. In the  
30 following, a satellite transponder as a communication channel  
is described more in detail with regard to Fig. 1.

A transponder of a communication satellite comprises a  
receiving antenna 1 for receiving an uplink signal sent from  
35 a ground station (not shown). An output signal of said  
receiving antenna 1 is fed to an input demultiplexer (IMUX) 3  
after frequency conversion in frequency converter 2. Said  
input demultiplexer 3 comprises several first filters 4-1 to  
4-n for separating individual signals within the signal from

the antenna. Typically, one filter is provided for each signal to be separated from the other signals received via said receiving antenna 1 and corresponds to a communication channel. The n output signals of said input demultiplexer 3 are fed to a corresponding number of high power amplifiers 5-1 to 5-n in each of which a traveling wave tube (TWT) is employed for amplifying the output signals of said input demultiplexer 3. As each of said high power amplifiers is normally operated in its saturation point, multiple signals would create intermodulation products and distortion of the signals. The amplifier output signals are passed through second filters 6-1 to 6-n which are part of an output multiplexer (OMUX) 7 combining the n amplifier output signals. The output signal of said output multiplexer 7 is fed to a transmitting antenna 8 for being transmitted to the desired area on the ground.

Hence, the demultiplexer (IMUX) consists of one filter per channel which separates the wanted signal from all other incoming signals. This separation is necessary in order to avoid multiple signals to reach the respective high power amplifier. Each channel has its own assigned high power amplifier (generally a traveling wave tube amplifier). As these high power amplifiers are normally operated in their saturation point, multiple signals would create intermodulation products, and thus distort the signals at the output of the satellites transmit antenna (down-link).

After the amplification, the signals are passed through a second filter (at the output multiplexer OMUX filter) which should avoid the broadband noise of the amplifiers to interfere with adjacent channels. Before being transmitted via the satellite's transmit antenna, all signals are combined again in the output multiplexer (OMUX).

The transponder filter characteristics are thus mainly determined by the IMUX and OMUX filters, which are in general realized in waveguide technology. Prior to launching a

satellite, the filters are designed and tested according to specifications. After the launch, the entire satellite, including the payload and especially the filters have to be tested in order to verify if during the launch phase, filters  
5 have been damaged. The beginning of life tests are thus a very crucial part before the operational life of a satellite.

For the beginning of life tests, the satellite is in general placed at an orbital position, which is not the final  
10 destination of the satellite. The reason for this is for instance that if the satellite contains transponders (back-up) which may interfere with operational transponders, the measurement signal on the satellite under test may create interference to payload signals of the operational  
15 satellites.

The orbital position on which a new satellite is placed during beginning of life tests is in general coordinated in such a way that no interference is created to any operational  
20 system. However, as the geostationary arc is more and more crowded with Ku-band satellites, it becomes more and more difficult to identify a slot, in which all bands of the satellite under test may be measured with high power signals.

25 Hence, when planning in-orbit tests on a communication satellite, a major constraint is to ensure that no radio interference can be generated, disturbing other communications satellite systems sharing the same frequency bands and, conversely, that the results of the satellite  
30 under in-orbit testing are not jeopardized by transmissions associated with other systems.

From the publication in International Journal of Satellite Communications, Vol. 13, 403-412 (1995); C. Moens and F.  
35 Absolonne: "ESA's in-orbit test facilities for communications satellites" those aspects were analyzed by a in-orbit test plan to cope with the following situations of the "maritime

satellite based on the European communication satellite system bus" - program:

5 (1) The presence of other maritime satellites resulted in non-permissible frequency slots in which it was not allowed to generate a carrier from the ground or from the satellite payload, e.g. the TDMA access channel and the search and rescue frequency band. This was accommodated in the software of the in-orbit testing computer by creating a frequency plan  
10 which inhibited use of the non-permissible frequency slots, such that test signals can only be generated in the permitted frequency channels.

15 (2) The second problem was created by the forward transponder containing an automatic level control function which keeps the output power constant irrespective of the transponder loading. The consequence is that the transmitted noise power increases, as transponder loading decreases, to reach an unacceptable level (from the interference point of view) when  
20 the transponder is not loaded. This difficulty has been overcome by ensuring a permanent minimum loading of the forward transponder. The loading was created by automatically up-linking two carriers, generated by dedicated synthesizers, during the inactive periods of the payload commissioning and  
25 acceptance phases. In the case of a malfunction in the C-band up-link during any in-orbit test, the minimum loading violation was detected by a specific computer program activating the loading carriers and aborting the ongoing test. The last result was for the European Space Operations  
30 Center to switch off the satellite payload.

Hence, according to conventional techniques the characteristics as amplitude response and group delay of the IMUX and OMUX filters is performed with a microwave link  
35 analyzer, which uses a frequency modulated carrier to measure amplitude response and group delay. The microwave link analyzer determines the group delay at a specific frequency by differentiating of the phase delay over frequency. As in a

channel using a high power amplifier like a TWTA, the amplitude to phase modulation (AM/PM) conversion can lead to erroneous measurements, the power of the MLA signal has to be far below the saturation point.

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The most important drawback of this conventional technique is that the measurement signal can create interference to an adjacent satellite system, due to the use of measurement signals having high spectral density. On the other hand, the measurement signal itself may be subject to noise and interference created by signals coming from adjacent satellites.

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Therefore, it is an object of the invention to simplify the inter-system coordination in a beginning of life test and avoiding the interference of adjacent satellite systems.

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This object is solved by the features of a method according to claim 1 and an apparatus according to claim 6.

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1. - modulating a clean carrier signal  $f(t)$  by spread spectrum modulation to generate a spreaded clean carrier signal  $s(t)$ ;

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- transmitting said spreaded clean carrier signal  $s(t)$  through said communication channel at a first predetermined level;

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- receiving a receive signal  $s'(t)$  corresponding to said spreaded clean carrier signal  $s(t)$  after having traveled through said communication channel;

- demodulating said receive signal  $s'(t)$  by spread spectrum demodulation to generate a despreaded carrier signal  $f'(t)$ ;

- 5        - determining characteristics of components of the communication channel on the basis of a comparison of said clean carrier signal  $f(t)$  and said despreaded carrier signal  $f'(t)$ .

10       Spread spectrum modulation and demodulation is a communication technique wherein the transmitted modulation is spread (increased) in bandwidth prior to transmission over the channel and then despread  
15       (decreased) in bandwidth by the same amount at the receiver. By far the most popular spreading techniques are direct sequence (DS) modulation and frequency hopping (FH) modulation.

20       A direct sequence modulation is formed by linearly modulating the output sequence of a pseudo random number generator onto a chain of pulses, each having a duration called the chip time. This type of modulation is usually used with binary phase-shift-keyed (BPSK) information  
25       signals. As such the modulated signal is formed by first multiplying (modulo-2) the pure information bitstream with the pseudo noise sequence and then modulating the phase of a clean carrier signal with the resulting signal.

30       At the receiver, either the PN waveform is already available or the receiver must first acquire the PN waveform. That is, the local PN random generator that generates the PN waveform at the receiver used for despreaded must be aligned (synchronized) within one  
35       chip of the PN waveform of the received signal. This is accomplished by employing some sort of search algorithm which typically steps the local PN waveform sequentially in time a fraction of a chip (e.g., half a chip) and at

each position searches for a high degree of correlation between the received and local PN reference waveforms. The search terminates when the correlation exceeds a given threshold, which is an indication that the alignment has been achieved. After bringing the two PN waveforms into coarse alignment, a tracking algorithm is employed to maintain fine alignment. The most popular form of tracking loops are the continuous time delay-locked loop and its time multiplexed version the tau-dither loop.

A frequency hopping modulation is formed by non-linearly modulating a chain of pulses with a sequence of pseudo randomly generated frequency shifts. This modulation signal is multiplied by a complex multiple-frequency-shift-keyed (MFSK) information signal. At the receiver, the sum of the transmitted signal and the channel interference is complex multiplied by the identical frequency hopping modulation which returns the transmitted signal to its original MFSK form. Analogous to the direct sequence case the receiver must acquire and track the frequency hopped signal so that the dehopping waveform is as close to the hopping waveform as possible.

2. Steps according to 1, wherein the spread spectrum modulation comprises the steps of

- generating a first pseudo noise signal  $PN(t)$ ;

- modulating said clean carrier signal  $f(t)$  with said first pseudo noise signal  $PN(t)$  to generate said spreaded clean carrier signal  $s(t)$ ;

and wherein the spread spectrum demodulation comprises the steps of

- correlating said receive signal  $s'(t)$  with said first pseudo noise signal  $PN(t)$  to generate said despread carrier signal  $f'(t)$ .

- 5     3. Steps according to 2, wherein said first pseudo noise signal  $PN(t)$  is a binary pseudo noise sequence.
- 10     4. Steps according to 3, wherein said binary pseudo noise sequence is generated by means of a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored.
- 15     5. Steps according to 2 to 4, wherein a chiprate of said first pseudo noise signal  $PN(t)$  is less than 5 MChip/s.
- 20     6. Steps according to 5, wherein a chiprate of said first pseudo noise signal  $PN(t)$  is less than or equal to 2,5 MChip/s.
- 25     7. Steps according to 2 to 6, wherein said correlating of said receive signal  $s'(t)$  and said first pseudo noise signal  $PN(t)$  is achieved by delaying said first pseudo noise signal  $PN(t)$  and multiplying the delayed first pseudo noise signal  $PN(t)$  and said receive signal  $s'(t)$ .
- 30     8. Steps according to 1 to 7, wherein the communication channel is a satellite communication channel set up by a transponder of a satellite.
- 35     9. Steps according to 8, wherein said first predetermined level is adjusted such that the spread clean carrier signal  $s(t)$  is received by an end user terminal of a communication channel of an adjacent channel with a level which is under the level of a received payload signal of said communication channel by a predetermined threshold.



5 In practice it has to be noted that the allocations of the frequency bands and the levels of the payload signals of adjacent satellite communication channels is well known and therefore it is possible to find an arrangement with another operator of the respective adjacent satellite communication channel in order to define the necessary threshold.

10 However, when determining the level for a clean carrier signal to be sent out by a ground station also the spatial separation or the spatial discrimination, respectively, of an antenna has to be considered. Thus, in a first step the allocation data of the frequency bands and the levels of the payload signals of adjacent  
15 satellites is taken as a basis for determining the given threshold. In a second step, furthermore the spatial separation characteristic both of the own ground station and the enduser terminals directed to an adjacent satellite are considered. Basically, in this situation  
20 two types of interference may happen. Either the users of an adjacent satellite receive in addition to the payload of the adjacent satellite the test signals via the enduser terminal or the own ground station also transmits a small portion of its signal to the adjacent  
25 satellite. The first type of interference is more likely to happen, as professional station normally have a much higher discrimination than enduser antennas just because of the different aperture. In this respect, the driving factor for dimensioning the measurement signal uplink  
30 power depends upon the spatial separation of both satellites and the related antenna discrimination, as well as on the level difference between the payload signal of the adjacent satellite and the measurement signal of the own satellite.

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10. Steps according to 9, wherein said first predetermined threshold is selected preferably between 15 dB and 25 dB.

11. Steps according to 9 or 10, wherein a measure for said first predetermined threshold is the processing gain which is defined by the ratio of the spectrum bandwidth of the first pseudo noise signal  $PN(t)$  and the data rate of the clean carrier signal  $f(t)$ , and wherein the data rate of the clean carrier signal  $f(t)$  is a result of the predetermined threshold and the predetermined spectrum bandwidth of the first pseudo noise signal  $PN(t)$ .

Hence, in accordance with this aspect of the present invention it is possible to reach almost any desired first predetermined level by selecting the data rate of the clean carrier signal  $f(t)$  accordingly.

12. Steps according to 1 to 8, wherein said first predetermined level of said spreaded clean carrier signal is adjusted by the following steps:

a) setting a preliminary level which corresponds to a lower limit in the communication channel;

b) processing said despreaded carrier signal  $f'(t)$  in order to determine actual characteristics of said despreaded carrier signal  $f'(t)$ ;

c) determining the deviation between the actual characteristics and predetermined desired characteristics of said despreaded carrier signal  $f'(t)$ ;

d.1) if the deviation is above a predetermined deviation: increasing the preliminary level by an incrementation parameter and repeating steps b) to d.1);

d.2) otherwise allocate the actual preliminary level to said first predetermined level.

Hence, in accordance with this aspect of the present invention no arrangement for a first predetermined

threshold is necessary. Rather the first predetermined level is adjusted by approaching a minimum level which is necessary to still receive sufficient characteristics of said despreaded carrier signal  $f'(t)$ . This is done by starting at a preliminary level which is assumed to the lower limit in the communication channel and according to which no interferences with adjacent communication channels will occur.

13. Steps according to 1 to 12, further comprising:

- modulating a reference carrier signal  $f_R(t)$  by spread spectrum modulation to generate a spreaded reference carrier signal  $s_R(t)$ ;

- transmitting said spreaded reference carrier signal  $s_R(t)$  through said communication channel at a second predetermined level;

- receiving a reference receive signal  $s_R'(t)$  corresponding to said spreaded reference carrier signal  $s_R(t)$  after having traveled through said communication channel;

- demodulating said reference receive signal  $s_R'(t)$  by spectrum demodulation to generate a despreaded reference carrier signal  $f_R'(t)$ ; and

- determining characteristics of components of the communication channel also on the basis of a comparison of said reference carrier signal  $f_R(t)$  and said despreaded carrier signal  $f_R'(t)$ .

This aspect of the present invention considers the fact that, during measurements in a satellite communication channel, due to the movements of the satellite the distance to the satellite can change. Also, during

measurements, due to atmospheric effects the attenuation of the path loss between the ground and the satellite can change. Therefore, e.g. in the case when the amplitude response and the group delay is determined by subtracting the amplitude response and the group delay at the center frequency from the respective values at other discrete frequencies, an error might occur due to the before mentioned satellite movements and atmospheric effects or other influences. These measurement errors can be compensated by the steps 13.

14. Steps according to 13, wherein the spread spectrum modulation comprises the steps of

- generating a second pseudo noise signal  $PN_R(t)$ ;
- modulating said reference carrier signal  $f_R(t)$  with said second pseudo noise signal  $PN_R(t)$  to generate said spreaded reference carrier signal  $s_R(t)$ ;

and wherein the spread spectrum demodulation comprises the steps of

- correlating said reference receive signal  $s_R'(t)$  with said second pseudo noise signal  $PN_R(t)$  to generate said despreaded reference carrier signal  $f_R'(t)$ .

15. Steps according to 13 or 14, wherein said second predetermined level is adjusted by a predetermined threshold below the level of a transmitted payload signal of an adjacent satellite communication channel.

16. Steps according to 15, wherein the predetermined threshold is selected preferably between 15 dB and 25 dB.

17. Steps according to 15 or 16, wherein a measure for the predetermined threshold is the processing gain which is defined by the ratio of the spectrum bandwidth of said second pseudo noise signal  $PN(t)$  and the data rate of the reference carrier signal  $s_R(t)$ , and wherein the data rate of the reference carrier signal  $s_R(t)$  is a result of the predetermined threshold and the predetermined spectrum bandwidth of the second pseudo noise signal  $PN(t)$ .

18. Steps according to 13 or 14, wherein said second predetermined level of said spreaded clean carrier signal is adjusted by the following steps:

a) setting a preliminary level which corresponds to a lower limit in the communication channel;

b) processing said reference receive signal  $s_R'(t)$  in order to determine actual characteristics of said reference receive signal  $s_R'(t)$ ;

c) determining the deviation between the actual characteristics and predetermined desired characteristics of said reference receive signal  $s_R'(t)$ ;

d.1) if the deviation is above a predetermined deviation: increasing the preliminary level by an incrementation parameter and repeating steps b) to d.1);

d.2) otherwise allocate the actual preliminary level to said second predetermined level.

19. Steps according to 14 to 18, wherein said second pseudo noise signal  $PN(t)$  is a binary pseudo noise sequence.

20. Steps according to 19, wherein said binary pseudo noise sequence is generated by means of a feed back shift

register or a memory device in which a sequence of values of a pseudo noise signal is stored.

21. Steps according to 14 to 20, wherein said correlating of said reference receive signal  $S_R'(t)$  and said second pseudo noise signal  $PN_R(t)$  is achieved by delaying said second pseudo noise signal  $PN_R(t)$  and multiplying the delayed second pseudo noise signal  $PN_R(t)$  and said reference receive signal  $S_R'(t)$ .

22. Steps according to 14 to 21, wherein said spreaded reference signal  $s_R(t)$  is transmitted through the same transponder of the satellite and said second pseudo noise signal  $PN_R(t)$  not correlated with said pseudo noise signal  $PN(t)$ .

23. Steps according to 13 to 22, wherein said spreaded reference signal  $s_R(t)$  is transmitted through a different transponder of the satellite.

24. Steps according to 1 to 23, wherein one of the characteristics of said communication channel is group delay and / or amplitude response.

25. Steps according to 1 to 24, wherein the characteristics of the input multiplexer (IMUX) and the output multiplexer (OMUX) in a communication satellite are determined.

Furthermore, the above-mentioned object is solved by an apparatus for determining characteristics of components of a communication channel, comprising the following means:

101. - first modulating means (10) for modulating a clean carrier signal  $f(t)$  by spread spectrum modulation to generate a spreaded clean carrier signal  $s(t)$ ;

- transmitting means (11, 12, 13) for transmitting said spreaded clean carrier signal  $s(t)$  through said communication channel at a first predetermined level;

5       - receiving means (13, 14) for receiving a receive signal  $s'(t)$  corresponding to said spreaded clean carrier signal  $s(t)$  after having traveled through said communication channel;

10       - demodulating means for demodulating said receive signal  $s'(t)$  by spread spectrum demodulation to generate a despreaded carrier signal  $f'(t)$ ; and

15       - determining means for determining characteristics of components of the communication channel on the basis of a comparison of said clean carrier signal  $f(t)$  and said despreaded carrier signal  $f'(t)$ .

20       102. Means according to 101, wherein the first modulation means (10) comprises

25       - first pseudo noise signal generating means (9) for generating a pseudo noise signal  $PN(t)$ , said clean carrier signal  $f(t)$  is modulated with said first pseudo noise signal  $PN(t)$  to generate said spreaded clean carrier signal  $s(t)$ ;

and wherein the demodulation means comprises

30       - first correlating means (14) for correlating said receive signal  $s'(t)$  with said pseudo noise signal  $PN(t)$  to generate said despreaded carrier signal  $f'(t)$ .

35       103. Means according to 102, wherein the first pseudo noise signal generating means (9) is designed for generating a binary pseudo noise sequence.

104. Means according to 103, wherein said first pseudo noise signal generating means (9) is a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored.

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105. Means according to 102 to 104, wherein a chiprate of said first pseudo noise signal  $PN(t)$  is less than 5 MChip/s.

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106. Means according to 105, wherein a chiprate of said first pseudo noise signal  $PN(t)$  is less than or equal to 2,5 MChip/s.

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107. Means according to 102 to 106, further comprising first delaying means (16) for delaying said first pseudo noise signal  $PN(t)$ .

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108. Means according to 101 to 107, wherein the communication channel is a satellite communication channel set up by a transponder of a satellite.

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109. Means according to 108, wherein said first predetermined level is adjusted such that the spread clean carrier signal  $s(t)$  is received by an end user terminal of a communication channel of an adjacent channel with a level which is under the level of a received payload signal of said communication channel by a predetermined threshold.

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110. Means according to 109, wherein said first predetermined threshold is selected preferably between 15 dB and 25 dB.

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111. Means according to 109 or 110, wherein a measure for said first predetermined threshold is the processing gain which is defined by the ratio of the spectrum bandwidth of the first pseudo noise signal  $PN(t)$  and the data rate of the clean carrier signal  $f(t)$ , and wherein



the data rate of the clean carrier signal  $f(t)$  is a result of the predetermined threshold and the predetermined spectrum bandwidth of the first pseudo noise signal  $PN(t)$ .

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112. Means according to 101 to 108, further comprising for adjusting said first predetermined level of said spreaded clean carrier signal:

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- setting means for setting a preliminary level which corresponds to a lower limit in the communication channel;

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- processing means for processing said despreaded carrier signal  $f'(t)$  in order to determine actual characteristics of said despreaded carrier signal  $f'(t)$  and for determining the deviation between the actual characteristics and predetermined desired characteristics of said despreaded carrier signal  $f'(t)$ ;

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- increasing means for increasing the preliminary level by an incrementation parameter if the deviation is above a predetermined deviation;

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- allocation means for allocating the actual preliminary level to said first predetermined level if the deviation is below or equal a predetermined deviation.

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113. Means according to 101 to 112, further comprising:

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- second modulating means (18) for modulating a reference carrier signal  $f_R(t)$  by spread spectrum modulation to generate a spreaded reference carrier signal  $s_R(t)$ ;

- transmitting means (11, 12, 13) for transmitting said spreaded reference carrier signal  $s_R(t)$  through said communication channel at a second predetermined level;

- receiving means (13, 14) for receiving a reference receive signal  $s_R'(t)$  corresponding to said spreaded reference carrier signal  $s_R(t)$  after having traveled through said communication channel; and

- demodulating means for demodulating said reference receive signal  $s_R'(t)$  by spectrum demodulation to generate a despreaded reference carrier signal  $f_R'(t)$ ; and

- determining means for determining characteristics of components of the communication channel also on the basis of a comparison of said reference carrier signal  $f_R(t)$  and said despreaded carrier signal  $f_R'(t)$ .

114. Means according to 113, wherein the second modulation means comprises

- second pseudo noise signal generating means (17) for generating a second pseudo noise signal  $PN_R(t)$ , said reference carrier signal  $f_R(t)$  is modulated with said second pseudo noise signal  $PN_R(t)$  to generate said spreaded reference carrier signal  $s_R(t)$ ;

and wherein the demodulation means comprises

- second correlating means (20) for correlating said reference receive signal  $s_R'(t)$  with said second pseudo noise signal  $PN_R(t)$  to generate a despreaded reference carrier signal  $f_R'(t)$ .

115. Means according to 113 or 114, wherein said second predetermined level is adjusted by a predetermined threshold below the level of a transmitted payload signal of an adjacent satellite communication channel.

116. Means according to 115, wherein the predetermined threshold is selected preferably between 15 dB and 25 dB.
- 5 117. Means according to 115 or 116, wherein a measure for the predetermined threshold is the processing gain which is defined by the ratio of the spectrum bandwidth of said second pseudo noise signal  $PN(t)$  and the data rate of the reference carrier signal  $s_R(t)$ , and wherein the data
- 10 rate of the reference carrier signal  $s_R(t)$  is a result of the predetermined threshold and the predetermined spectrum bandwidth of the second pseudo noise signal  $PN(t)$ .
- 15 118. Means according to 113 or 114, further comprising for adjusting said second predetermined level of said spreaded clean carrier signal:
- 20 - setting means for setting a preliminary level which corresponds to a lower limit in the communication channel;
- 25 - processing means for processing said reference receive signal  $s_R'(t)$  in order to determine actual characteristics of said reference receive signal  $s_R'(t)$  and for determining the deviation between the actual characteristics and predetermined desired characteristics of said reference receive signal  $s_R'(t)$ ;
- 30 - increasing means for increasing the preliminary level by an incrementation parameter if the deviation is above a predetermined deviation;
- 35 - allocation means for allocating the actual preliminary level to said second predetermined level if the deviation is below or equal a predetermined deviation..

119. Means according to 114 to 118, wherein the second pseudo noise signal generating means (9) is designed for generating a binary pseudo noise sequence.

5 120. Means according to 119, wherein said second pseudo noise signal generating means (9) is a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored.

10 121. Means according to 114 to 120, further comprising second delaying means (19) for delaying said second pseudo noise signal  $PN_R(t)$ .

15 122. Means according to 114 to 121, wherein said spreaded reference signal  $s_R(t)$  is transmitted through the same transponder of the satellite and said second pseudo noise signal  $PN_R(t)$  not correlated with said pseudo noise signal  $PN(t)$ .

20 123. Means according to 113 to 122, wherein said spreaded reference signal  $s_R(t)$  is transmitted through a different transponder of the satellite.

25 124. Means according to 101 to 123, wherein one of the characteristics of said communication channel is group delay and / or amplitude response.

30 125. Means according to 101 to 124, wherein the characteristics of the input multiplexer (IMUX) and the output multiplexer (OMUX) in a communication satellite are determined.

35 All in all, with the method according to the invention using spread spectrum signals, one will be able to perform measurements without creating interference to, or being interfered by channels of adjacent satellites.

If a pseudo random noise signal is used, it can be generated by feed back shift registers as described in Bernard Sklar: Digital Communications Prentice Hall 1988, for example. The pseudo random noise signal has the important characteristic of a very sharp autocorrelation function at zero delay. This allows to regenerate exactly the time delay between a locally generated PN signal and the (delayed) received signal.

For measuring the amplitude and group delay of a communications channel, one needs to choose the chiprate (which determines the overall bandwidth of the PN signal) of the PN signal such that the modulated PN signal is narrow in comparison with the expected peaks in group delay of the communication channel. In order to be able to measure during normal operation without disturbing any payload signal, it is important that the measurement signal level is sufficiently below the level of said payload signal (e.g. about 25 dB).

Under these conditions, one can sweep the carrier of the PN signal in frequency from the lowest to the highest frequency of the communications channel, and measure the amplitude of the correlation peak and the time delay of the received and demodulated PN signal at discrete frequencies. The amplitude and time delay correspond in this case to the amplitude response and the group delay of the communications channel at the selected frequencies.

A variation of the described method for measuring the group delay consists of measuring the phase of the reconstructed carrier of the spreaded signal at a specified frequency. By measuring the phase of the reconstructed carrier of the spreaded at a frequency very close to the first frequency, it is possible to approximate the group delay at the frequency located exactly in the middle of both measurement frequencies by calculating the phase difference and dividing by the frequency difference.

Besides this conventional technique, in the present case it is possible to measure the group delay at a certain frequency directly via the delay of the despreaded carrier signal  $f'(t)$  in comparison with a pseudo noise signal  $PN(t)$  which is fed  
5 directly from the modulating means to the determining means.

For the characterization of the communications channel, the most interesting values are the amplitude response and the group delay with respect to the center frequency of the  
10 channel. This is easily obtained in subtracting the measurements at center frequency from all the measurements.

Another characteristic which can be measured by the method according to the invention is the change of the frequency of the carriers received on the uplinks to that on the downlinks  
15 (e.g. from 14 GHz to 11 GHz).

The measurements can be performed with one measurement signal and one frequency signal, but of course the use of multiple measurement signals at different frequencies in parallel is  
20 possible, thereby increasing the measurement performance and the speed for carrying out the necessary measurements.

In the case of a satellite communication channel (a transponder), one has to face the problem that during measurement, the distance to the satellite can change due to the movements of the satellite, or that due to atmospherical effects the attenuation of the path loss between the measurement instrument and the satellite can change.  
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30 These problems can be easily solved in using a reference signal which may be located at a fixed frequency somewhere on the same transponder (or even on a neighboring transponder but on the same satellite). If the measurement signal is swept in frequency over the transponder, while the reference  
35 signal is remaining at a fixed frequency, one obtains the wanted amplitude response and group delay of the communications channel by subtracting the values of the

reference signal from the measurements signal at the corresponding time.

5 In the following an embodiment of the invention will be described in greater detail and with reference to the drawings.

Fig. 1 shows a schematic diagram of a transponder of a communication satellite;

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Fig. 2 shows a schematic diagram of a first embodiment of an apparatus according to the invention;

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Fig. 3a and 3b show diagrams representing measurement result;

Fig. 4 shows a schematic diagram of a second embodiment of an apparatus according to the invention.

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Fig. 5 shows a schematic diagram to illustrate the situation of possible interference types.

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For the purpose of describing an embodiment of the invention, Fig. 1 shows the components of a transponder in a communication satellite as an example for a communication channel which was already explained above.

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Since the filters provided in the input demultiplexer (IMUX) 3 and the output multiplexer (OMUX) 7 have a strong influence on the performance of the transponder, the method according to the invention will be explained in following with respect to measuring two specific characteristics, namely amplitude response and group delay, of these components of the transponder communication channels, the method of the invention being especially suitable for this application.

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However, the same or other characteristics of other components of the communication channel can be determined by means of the method and the apparatus according to the invention.

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According to the invention, in a ground station as shown in Fig. 2, a pseudo noise signal  $PN(t)$  is generated by means of a pseudo noise signal generator 9, for example, a feed back shift register or a memory device in which a sequence of values of a pseudo noise signal is stored. The pseudo noise signal  $PN(t)$  has a very sharp autocorrelation function at zero delay. This allows to determine the time delay between the locally generated pseudo noise signal  $PN(t)$  and a received signal which is delayed due to the propagation time. A clean carrier signal  $f(t)$  having a variable frequency, which is varied as explained further below, is modulated with said pseudo noise signal  $PN(t)$  by means of a first multiplier 10 to form a spreaded clean carrier signal  $s(t) = PN(t) \times f(t)$ . The chiprate of the pseudo noise signal  $PN(t)$ , which determines the bandwidth of this signal, is chosen such the bandwidth of the spreaded clean carrier signal  $s(t)$  is narrow in comparison with the expected peaks in group delay of the communication channel. Typically, the chiprate of the pseudo noise signal may be chosen less than 5 Mchip/s.

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The spreaded clean carrier signal  $s(t)$  is fed to an upconverter 11 and via a high power amplifier 12 to an antenna 13 which transmits the spreaded clean carrier signal  $s(t)$  to the transponder of the communication satellite under test. However, from the viewpoint of a user transmitting a payload signal to the satellite, the transponder remains usable during the test and can be continuously supplied with a payload signal.

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According to the invention, the level of the transmitted spreaded clean carrier signal  $s(t)$  is sufficiently below the level of the payload signal, for example about 15 to 25 dB or more, such that the payload signal is not notably



deteriorated. For this reason, the spreaded clean carrier signal  $s(t)$  can be transmitted while the communication channel is in use, i.e. simultaneously with a payload signal being transmitted to the transponder of the satellite from the same or from another ground station.

The frequency of the clean carrier signal  $f(t)$  is changed such that it sweeps from the lowest to the highest frequency of the pass band of the filters in the satellite transponder, or any other component of a general communication channel under test. The spreaded clean carrier signal  $s(t)$  has a narrow bandwidth due to the pseudo noise signal  $PN(t)$  such that amplitude response and group delay of the communication channel can be determined at selected discrete frequencies, as will be described in the following.

In the embodiment, antenna 13 is also used to receive the signal re-transmitted by the transponder of the satellite, in other words the signal which has traveled through the communication channel. The output signal of antenna 13 is passed through a downconverter 14 to obtain a receive signal  $s'(t)$  which is fed to a second multiplier 15 receiving also the same but delayed pseudo noise signal  $PN(t)$ . The delay is generated by delaying means 16 which are set such that the output of the second multiplier 15 becomes maximum. Thereby, the receive signal  $s'(t)$  is multiplied, in other words correlated with the very same pseudo noise signal  $PN(t)$  which has been used for generating the spreaded clean carrier signal  $s(t)$  and a despreaded carrier signal  $f'(t)$  is obtained which is only delayed and attenuated in comparison with the clean carrier signal  $f(t)$ . Thus, the amplitude response, which corresponds to the attenuation of the despreaded carrier signal  $f'(t)$ , and the group delay, which corresponds to the delay of the despreaded carrier signal  $f'(t)$ , of the transponder of the satellite, as an example of a general communication channel, can easily be determined. The runtime of a narrowband signal at its center frequency corresponds to the group delay of the filters if the phase can be linearly

approximated in the signal bandwidth. The chiprate of the PN signal is determined accordingly.

As far as communication satellites are concerned, it is sufficient to determine the amplitude response and group delay over the pass band of a transponder only relative to the amplitude response and group delay at the center frequency of the pass band. Therefore, it is sufficient to delay the pseudo noise signal  $PN(t)$  such that the amplitude of the despread carrier signal  $f'(t)$  becomes maximal and to subtract the amplitude and the delay at the center frequency from the amplitude and the delay at any other frequency in the pass band, respectively.

Fig. 3a and 3b show typical measurement result for amplitude response (Fig. 3a) and group delay (Fig. 3b) as obtained by the method according to the invention.

In the case of a satellite communication channel, i.e. a transponder, it should be noted that, during measurements, due to the movements of the satellite the distance to the satellite can change. Also, during measurements, due to atmospheric effects the attenuation of the path loss between the ground station and the satellite can change.

Since in the above embodiment the amplitude response and the group delay is determined by subtracting the amplitude response and the group delay at the center frequency from the respective values at other discrete frequencies, an error might occur due to the before mentioned satellite movements and atmospheric effects or other influences.

As shown in Fig. 4, a reference signal  $s_R(t)$  can be used to compensate the before mentioned measurement error. In Fig. 4 the same reference signs are used for those parts already described above and reference is made to the above description of these parts. The reference signal  $s_R(t)$  is generated by means of a third multiplier 18 which receives a second pseudo noise signal  $PN_R(t)$ , which is not correlated

with the first pseudo noise signal  $PN(t)$  and which is generated by a second pseudo noise generator 17, and a reference carrier signal  $f_R(t)$  which may be located at a fixed frequency somewhere within the pass band of the same transponder or in the pass band of another transponder on the same satellite having a different center frequency. Like in the above embodiment, a spreaded reference carrier signal  $s_R(t)$  is transmitted to the satellite and the reference receive signal  $s_R'(t)$  is multiplied with the second pseudo noise signal  $PN_R(t)$  to obtain the despreaded reference signal  $f_R'(t)$ . While the measurement signal is swept in frequency over the transponder pass band, the frequency of the reference carrier signal  $f_R(t)$  remains at a fixed frequency. Therefore, a corrected amplitude response and group delay of the communications channel can be obtained by subtracting the values of the reference signal from the values of the measurement signals at the respective time.

A variation of the described measuring the group delay consists of measuring the phase of the reconstructed carrier of the spreaded signal at a specified frequency very close to the first frequency, it is possible to approximate the group delay at the frequency located in the middle of both measurement frequencies by calculating the phase difference and dividing by the frequency difference.

Only pseudo noise signals have been discussed above because these signals can be generated comparatively easily. However, true noise signals can be used in the method and the apparatus according to the invention. Properties of true and pseudo noise signals are well known to those skilled in the art and are described, for example in Bernard Sklar, "Digital Communications - Fundamentals and Applications", Prentice Hall, 1988.

Fig. 5 shows a schematic diagram to illustrate the situation of possible interference types. Fig. 5 assumes the situation

when a satellite 31 was just launched and is now subject of various types of tests in its beginning of life phase. The responsible station for carrying out these tests is the ground station 30. While carrying out these tests it has to be ensured that the communication channels of adjacent satellites are not affected. Thus, satellite 32 represents possible adjacent satellites which could be affected by the measurements carried out for satellite 31. Signals sent out by satellite 32 are received by a plurality of enduser terminals which are represented by the enduser terminal 33.

Basically, two types of interference from the measurement signals on satellite 31 to satellite 32 and the corresponding enduser terminals 33 may happen: Either the users of satellite 32 receive through their (small) dish the measurement signal directly via satellite 31, i.e. in addition to the payload signal of satellite 32, or the station 30 transmits also a small portion of its signal to the adjacent satellite 32. The first type of interference is more likely to happen, as professional stations normally have a much higher discrimination than enduser antennas just because of the different size of the aperture. In this respect, the driving factor for dimensioning the measurement signal uplink power depends upon the spatial separation of both satellites and the related antenna discrimination, as well as on the level difference between payload signal B and the measurement signal A.

It has to be noted, that the invention also allows to carry out the necessary measurements with an antenna having a smaller aperture than a conventional antenna of the own earth station 30. Due to the decreased spatial separation of a smaller type of antenna the interference type 2 might occur. However, this is not critical as long as the spread clean carrier signal  $s(t)$  is received by an end user terminal 33 of a communication channel of satellite 32 with a level which is under the level of a received payload signal of said communication channel by a predetermined threshold.